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With the continued proliferation of emitters on the modern battlefield, the need for high intensity RF effects RDT&E is increasing. As RF strength parameters increase, hazards to mission systems and test personnel will increase. Many tools are available today to assess system performance in harsh or hostile RF environments. To support RF effects testing, DOD has developed numerous Electromagnetic Environmental Effects (E^3) and EW simulators and RDT&E facilities. This paper discusses the combination of a reverberation (mode-stir) chamber, and popular subsystem test tool, with a Transverse Electromagnetic (TEM) cell, as a large-scale system level evaluation capability. In order to perform RDT&E on large complex weapons systems, this capability will be integrated into an existing Installed System Test Facility. This facility will permit comprehensive evaluations of system safety and survivability to extreme RF environments in a fast, efficient, controlled manner, using open and closed loop test technologies.

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Joint Army-Navy Development of the Transverse Electromagnetic / Mode-Stir (TEMMS) Chamber for Large System RF Effects RDT&E.

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Introduction.

With the continued proliferation of emitters on the modern battlefield, the need for high intensity Radio Frequency (RF) effects Research, Development, Test, and Evaluation (RDT&E) is increasing. As RF strength parameters increase, hazards to mission systems and test personnel will increase. Many tools are available today to assess system performance in harsh or hostile RF environments. To support RF Effects testing, DOD has developed numerous Electromagnetic Environmental Effects (E^3) and Electronic Warfare (EW) simulators and RDT&E facilities. This paper discusses the combination of a reverberation (mode-stir) chamber, a popular subsystem test tool, with a Transverse Electromagnetic (TEM) cell, as a large-scale system level evaluation capability. In order to perform RDT&E on large complex weapons systems, this capability will be integrated into an existing Installed System Test Facility. This facility will permit comprehensive evaluations of system safety and survivability to extreme RF environments in a fast, efficient, controlled manner, using open and closed loop test technologies.

Reverberation Chambers.

The present DOD E^3 and EW facilities that support high-power RF RDT&E include designated outdoor test ranges, anechoic chambers, TEM cells, and reverberation (mode-stir) chambers. Generally, in DoD, the first two types of facilities support large weapon system testing and the latter two support component and small systems or subsystems testing.

High Power RF illumination of large weapon systems using preset RDT&E techniques is difficult, expensive, and limited. The reverberation chamber provides 360°, 3-axis coverage of the test object at all aspect angles and polarizations (Figure 1).

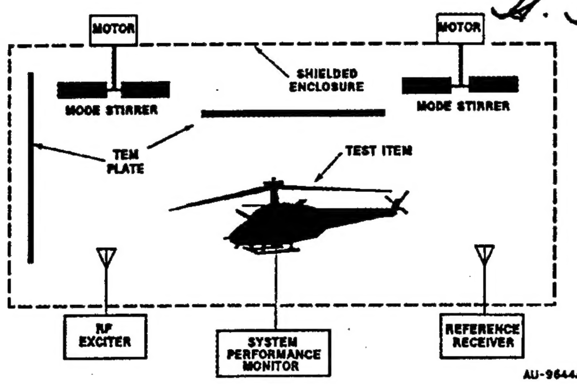

Figure 1. Description of a Reverberation Chamber.

Reverberation chambers are frequently compared to "microwave ovens". The analogy stems from the fact that both "stir" frequencies to uniformly radiate the chamber volume. Reverberation chambers typically have an effective range from a few hundred Megahertz to the 10's of Gigahertz, with a power efficiency that allows relatively small RF sources to develop very intense field strengths within the chamber. At the lower frequencies, when reverberation chambers become ineffective the chamber's frequency range can be extended even lower by transitioning it into a TEM cell. Presently, at the higher power RF levels, large systems must be tested at one aspect angle, frequency and polarization at a time (Figure 2). This spot illumination is becoming inadequate or inefficient in many test operations. Figure 3 illustrates this fact very effectively. As shown on this graph, the efficiency of mode-stir over spot-illumination increases considerably as the frequency increases. The TEMMS efficiency advantage still holds at lower frequencies.

Figure 2. Comparison of RF Illumination Techniques.

Over the past ten years, technology advances and the need to increase the effectiveness and efficiency of high-power RF testing have driven the need for reverberation chambers as a test tool for larger systems. The Naval Surface Warfare Center, (NSWC) in partnership with the National Institute of Standards and Technology (NIST), has been actively involved in developing reverberation chamber theory and techniques. As a result of the NSWC and NIST

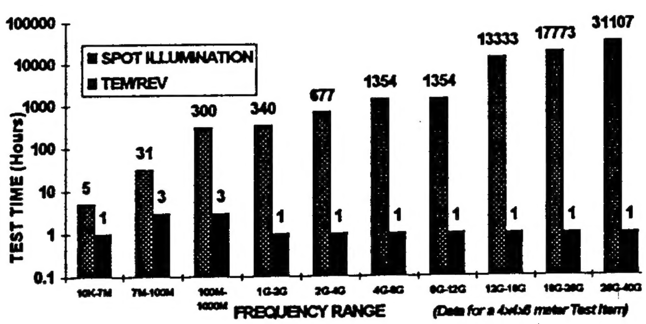

Figure 3. Efficiency of Mode-Stir vs. Spot Illumination

efforts, reverberation chamber techniques have been incorporated into commercial standards used for certifying commercial aircraft avionics. The Australian Military, after consulting with NSWC and NIST constructed a reverberation chamber large enough (20.7 m x 10.9 m x 6.1 m) to evaluate a small, fighter-sized aircraft. In addition, NASA Langley Research Center, working with NIST and NSWC, has deployed a facility capable of assessing fuselage sections of commuter sized aircraft. Additionally, there has been significant proliferation in smaller reverberation chambers for RF testing. Reverberation chambers are becoming a standard test technique in commercial RF and DOD immunity testing. General Motors Corp. has imposed the requirement on all of its electronic suppliers to use only reverberation chamber techniques for testing at frequencies above 400 MHz.

Joint Army-Navy Transverse Electromagnetic / Mode-Stir (TEMMS) Reverberation Facility.

The DOD Central T&E Improvement Program (CTEIP) has been considering reverberation chambers for some time. The Army[1] established a requirement[1] and proposal[2] for a large Transverse Electromagnetic/Reverberation (TEM/REV) facility in 1992. The Air Force[3] and the Navy[4] supported this need. Although the project reached the 65% design stage, it did not advance to the final construction phase. The Army's PM-ITTS of STRICOM and the NAWCAD are now jointly sponsoring a derivative of this Army proposal. The proposed large Transverse Electromagnetic/Mode-Stir (TEMMS) Chamber[5], is based on the original Army's TEM/REV proposal in order to capitalize on the earlier effort.

The TEMMS will have several improvements over the initial TEM/REV project. The Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD, a DOD Major Range and Test Facility Base (MRTFB) has been proposed as the location for the following reasons: NAWCAD has a MOA with TECOM, Aberdeen Proving Grounds to support testing. Army and Navy E^3 Aviation RDT&E is routinely conducted at Patuxent River. NAWCAD has a large, modern and diverse RF RDT&E support complex to support TEMMS: This includes a small Anechoic Chamber, a large shielded hangar, and an outdoor test pad which support E^3 and EW RDT&E. A new, larger Anechoic Chamber will be available May, 1999. NAWCAD has a very large and complex Installed Systems Test Facility, incorporating a Manned Flight Simulator and a DOD high power computing center for high level modeling and simulation (Figure 4). The large in-place E3 and EW RDT&E simulation, stimulation,

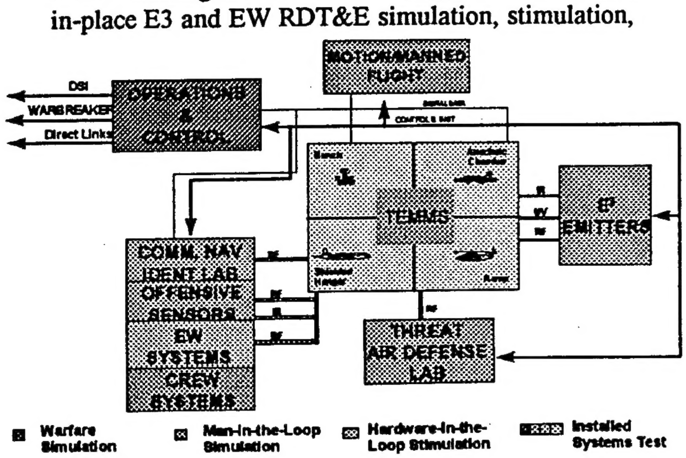

Figure 4. TEMMS Interfaces to ACETEF

measurement, modeling and analysis capabilities will reduce TEMMS long-term investment requirements, while increasing effectiveness. All TEMMS related facilities are co-located within the same complex.

Integrating TEMMS into an Installed System Test Facility (ISTF).

The TEMMS would provide a large 127'x 113'x 50' shielded chamber and supporting equipment to illuminate full scale weapon systems such as tanks, vehicles, C^4I elements, helicopters, and aircraft up to the size of a Navy P-3 aircraft. This capability can support special access classified projects up to the Top Secret security level. The controlled electromagnetic environment is provided over the frequency range of 10 kHz to 40 GHz. The average electromagnetic field levels will range from 10V/m to 400 V/m with peak field to 80,000 V/m. Interfaces to data acquisition and data processing, man-in-the-loop test/simulation capabilities, databases, and the Air Combat Environment T&E Facility (ACETEF) will be available (Figure 5). Also, an interface with MIL-STD-1553 MUX Bus for the control of aircraft/weapons systems will be used to simulate mission profiles and to exercise specific systems. This capability will provide uniform illumination of full-scale aircraft by using mode-tuned and/or mode-stirred techniques. TEMMS technology is unique, and will provide DOD with a capability to test to high power levels while minimizing test setup time and rotation of the test aircraft or illumination source. This shielded volume will also be used as a TEM cell to test to high powers at the lower end of the frequency range. The TEMMS facility will be unique and will provide all three services and other DOD agencies with a one-of-a-kind test capability. Such a facility would complement present high power test capabilities and support a wide range of weapon systems ranging from tanks, mobile vehicles, transportable C^4I systems, helicopters, to tactical fighters. The TEMMS will support a variety of

Figure 5. Centralized Location of TEMMS at NAWCAD.

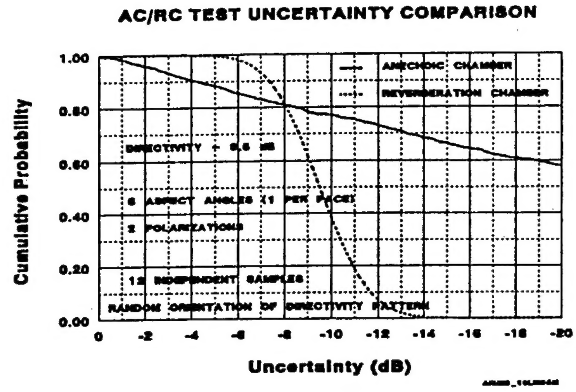

Figure 6. Chamber Uncertainty Comparison Anechoic vs. Reverberation Testing.

electronic attack and defense technologies; RDT&E of the effects of E^3, RF Weapons, and EW environments will be the mainstay of this chamber. Enlarging the chamber to accommodate strategic aircraft is also under consideration.

TEMMS Impacts, Limitations and Issues.

If TEMMS is not deployed, RF testing will become less effective as the threats and operational requirements continue to grow. Specific high-risk impacts to the acquisition process include large test result uncertainties, extended test periods, unavailability of test facilities, undetected susceptibilities and vulnerabilities, and the fielding of inadequately tested systems. Uncertainty in test results, (i.e. statistical deviations from expected values in test results), are of great concern to testers. Figure 6 shows a comparison of uncertainty (dB) in the well-established anechoic chamber to the reverberation chamber. Without going into detail, this plot shows the cumulative probability (i.e. the probability of obtaining an uncertainty/deviation less than the expected value) as a function of uncertainty. For uncertainty values below –8dB, the reverberation chamber sharply outperforms the anechoic chamber. For uncertainty values above –8dB, the difference in the chances of obtaining these values is less than 7%, but in favor of the anechoic chamber. However, the chance of getting an uncertainty of less than –14dB is effectively zero for the TEMMS, but can be as high as 60% for the anechoic chamber.

The way to reduce uncertainty is to increase the number of samples (i.e. increase the amount of testing). As expensive as testing is, increasing it to reduce uncertainty is unacceptable. Consequently, when compared to anechoic chambers, the TEMMS is able ability to significantly reduce uncertainty, in a

shorter test period, thus highlighting its benefits. These issues will be compounded by the costs needed to increase the capabilities of our present test capabilities as new threats and requirements are identified.

Although considered an excellent RF test tool, the TEMMS does not replace existing capabilities, but rather augments them. TEMMS is an excellent engineering tool for demonstrating resistance to RF interference. TEMMS will screen systems for problems and identify potential susceptibilities and vulnerabilities. After a weakness is identified it will be necessary to perform classic RF testing to determine whether the actual susceptibility will occur during operational scenarios. Due to the reflective nature of TEMMS, not all modulations and waveforms may be adequately simulated as a test environment. Because TEMMS is an Installed System Test Facility; all equipment can be operated through externally provided conditioned power and hydraulics, except the engines.

The state-of-the-art technology for large-scale reverberation chambers is low risk. The large (180' x 180' x 60') anechoic chamber at Patuxent River was evaluated as a reverberation chamber prior to installation of the absorber material. Although the chamber was slightly larger than the proposed reverberation chamber and was not designed to be a reverberation chamber and, as constructed, would not make a suitable reverberation chamber, it did yield results consistent with reverberation chamber theory. (Figure 7).

One of the most difficult and expensive aspects of developing a new facility like the TEMMS, is to integrate it into the Man-in-the-loop architecture. Fortunately, this architecture is already in place and

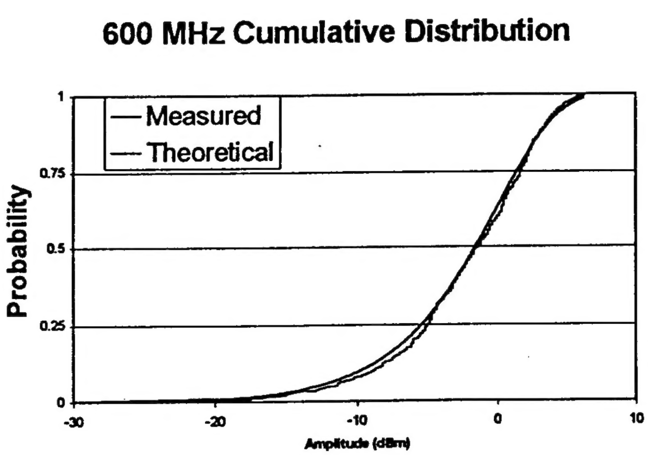

Figure 7. Measured vs. Theoretical Distribution of Fields in Large Shielded Enclosure.

requires little additional modification to support reverberation chamber testing. The knowledge base for reverberation chambers has progressed beyond "Does it work?" and is now concerned with 'How do we optimize its use?". Large, reverberation test chambers are presently in use in the automotive industry, several others are in progress or being planned, and smaller chambers are proliferating as a mainstay in component and subsystem E^3 testing. Statistically based reverberation chamber test techniques have become a useful tool in support of EMC testing of large aircraft. The Army design effort addressed and solved most of the equipment and basic application issues. SBIR's and ongoing development at NAWCAD and NSWC, Dahlgren, VA continue to address how to increase reverberation chamber applications and maximize efficiencies.

Conclusions.

The TEMMS facility will effectively address the key E^3, RF Weapons and EW RDT&E issues. This will benefit the DoD in several ways: reduced test cost, increased personnel safety, significantly less hazards to other equipment/aircraft, less aircraft test time, more thorough tests, more realistic tests, reduced manpower, flexible test scheduling, secure tests, all weather test capability, reduced training for facility operators, and high quality tests. All of these payoffs come about because the facility provides efficient, 360°, 3-axis environments, is fully automated, is indoors, and, uses state-of-the-art equipment, test technology, and methods.

Failure to develop this capability will result in the following: inability to test aircraft to full threat environments; inability to test aircraft vulnerability to high power microwave weapons; and increased risk in adequately assessing aircraft system responses to electromagnetic environments. Not developing TEMMS will impact the aircraft weapon system development RDT&E process and leave many potential RF susceptibilities and vulnerabilities unidentified prior to operational deployment.

At present there are no other facilities within DoD that come close to providing the range of test capabilities required. All services are facing the same future of increasing operational RF environments; new advanced weapon threats; the increased use of composites, microelectronics, and commercial equipment; and emerging test requirements such as those imposed by the new Federal Aviation Regulation Rules. Starting the proposed program now will provide the appropriate MRTFB facility that can be used by all services and other government agencies in meeting their E^3 test requirements.

References

1. Requirements Document for Transverse Electromagnetic Reverberation (TEM/REV) Test Facility, April 1992.

2. Letter, Department of The Army, Office of the Program Executive Officer, Aviation, subject: Proposed Construction of a Transverse Electromagnetic / Reverberation Chamber, 21 March 1991.

3. Letter, Department of The Air Force, DCS Test and Resources, subject: Transverse Electromagnetic / Reverberating (TEM/REV) Chamber, dated 12 June 1991.

4. Personal Letter to MG George Akin, U.S. Army Test and Evaluation Command from: Commander Naval Air Test Center supporting TEM/REV Chamber, dated 19 April 1991.

5. DOD Central T&E Investment Program (CTEIP), Transverse Electromagnetic / Mode-Stir Facility (TEMMS), Navy Solution 1242, updated, 2 June 1997

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Joint Army-Navy Proposal for a Transverse Electromagnetic Mode Stirred TEMMS Facility

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Aircraft Division
NAVAL AIR WARFARE CENTER

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BACKGROUND

- Transverse Electromagnetic Reverberation Chamber Program Initiated in 1988/89 to Test Army Aviation Systems
- Army/Electronic Proving Ground Lead at Ft Huachuca as Equipment-In-Place
- 1/10 Scale Prototype Built Which Validated Technology
- 65 % Design Completed for Full Scale Facility

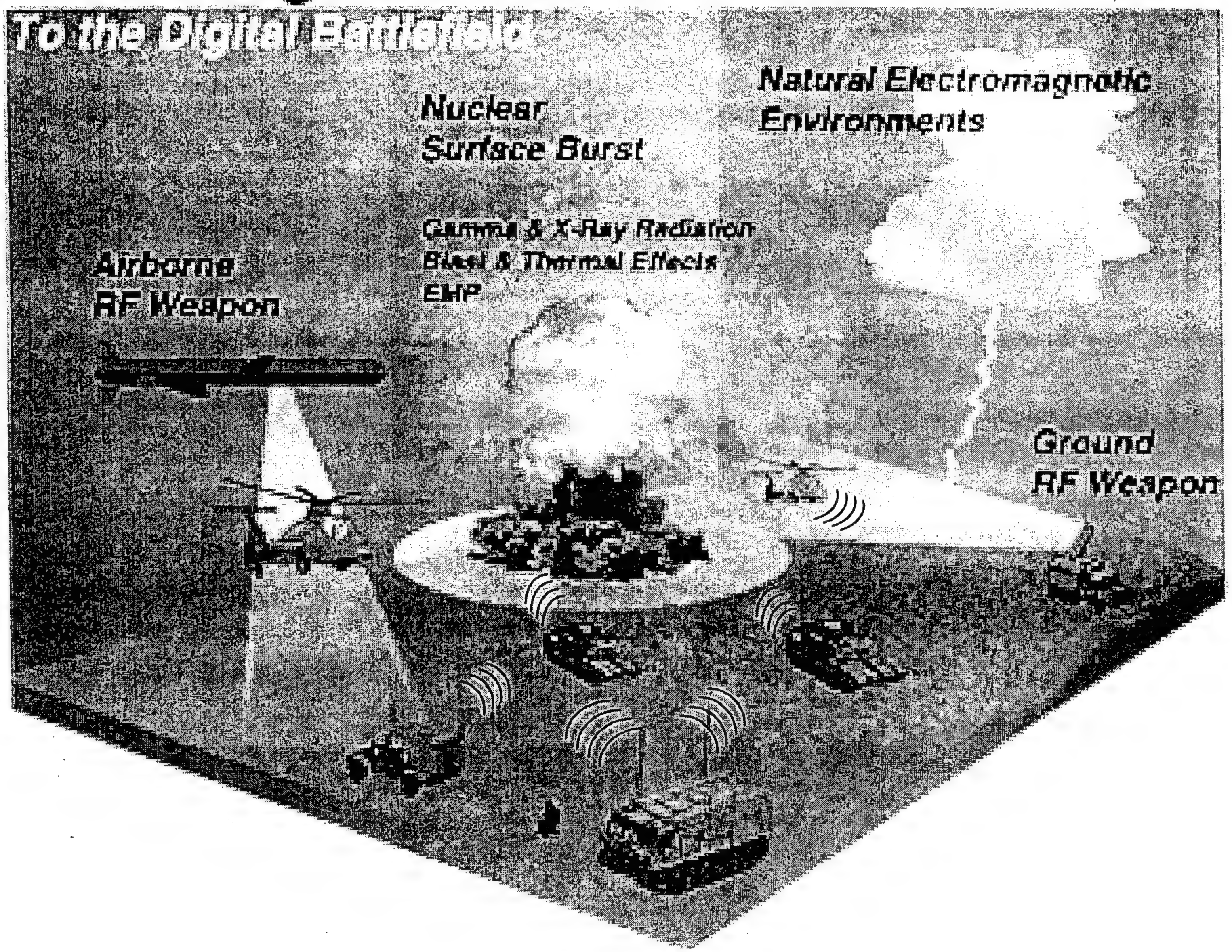
BACKGROUND (Cont.)

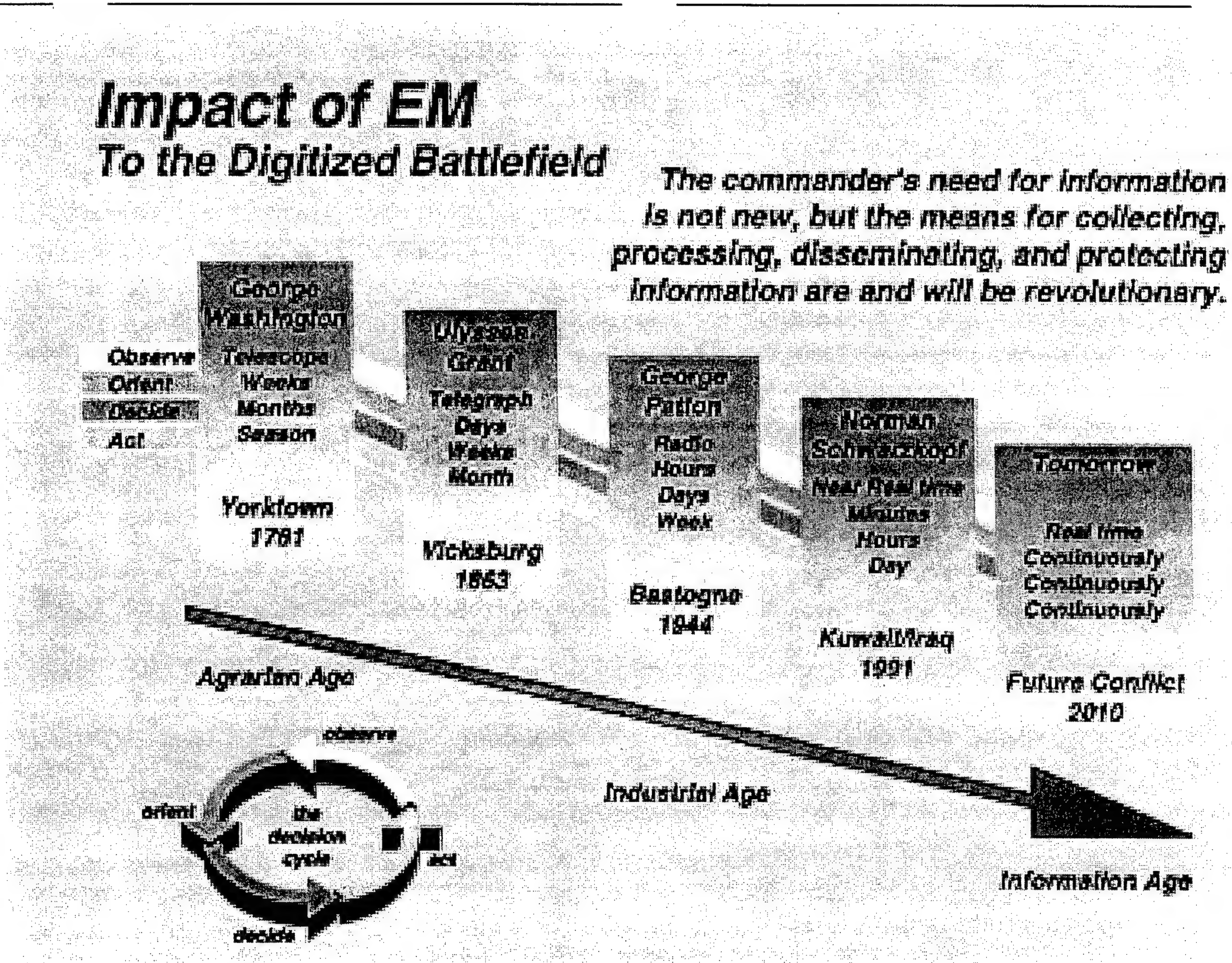
- Facility determined not “Equipment-in-Place”
- Confusion between the TEM/REV Facility and Large Anechoic Chamber proposed at Pax River
- Program Lost Tri-Service Support and needed MCA approval/funds
- Program Died/Killed in 1993

WHAT'S HAPPENING?

- Future battlefield infiltrated with many emitters - Digitization of the Battlefield, Combat ID, Technology Insertion, Force XXI Solider
- Every New Combat System with Electronic Control
- Army/Navy E3 Aviation T&E Consolidated at Pax River

Electromagnetic Threats





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SO WHAT?

- Still a <u>Need</u> for a **Large** Chamber that can evaluate the performance of future **Large** Weapons Systems in the E3 Environments
- Should have the Capability for Man-In-The-Loop and Co-Located with Complimentary Capabilities
- Navy Submitted Needs/Solution for Mode Stirred Chamber for Aircraft Testing in 1996

T&E ISSUE'S

- High Power Illumination of Large Weapon Systems Using Present Techniques Is Difficult, Expensive, and Limited
- As EM Field Strength Requirements Increase, Hazards To Test Personnel, Other Equipment And The Overall Environment Increase
- Present Intersystem E^3 Testing Provides Limited Measurements
- Schedule, Cost Effectiveness, Test Fidelity and Growth Potential of E^3 Test Tools

NEED

- Illumination of Full-Scale Combat Systems in a Controlled, Electromagnetic Environment

  - Frequency Range - 10 kHz to 40 GHz
  - Average Field Levels - 10 V/M to 400 V/M
  - Peak Field Levels - 2,000 V/M to 80,000 V/M
  - Coupling Measurements
  - Support Man-In-The-Loop Testing
  - Interface With Other Laboratories

<u>Related NTEPP Needs</u>

•N-95-1242-0-95-N	MSCAT
•N-90-1133-R-95-N	EMTTEF
•N-90-1237-R-95-N	EMEGS
•N-90-1029-R-95-N	E^3 FACILITY

PROPOSED PROGRAM

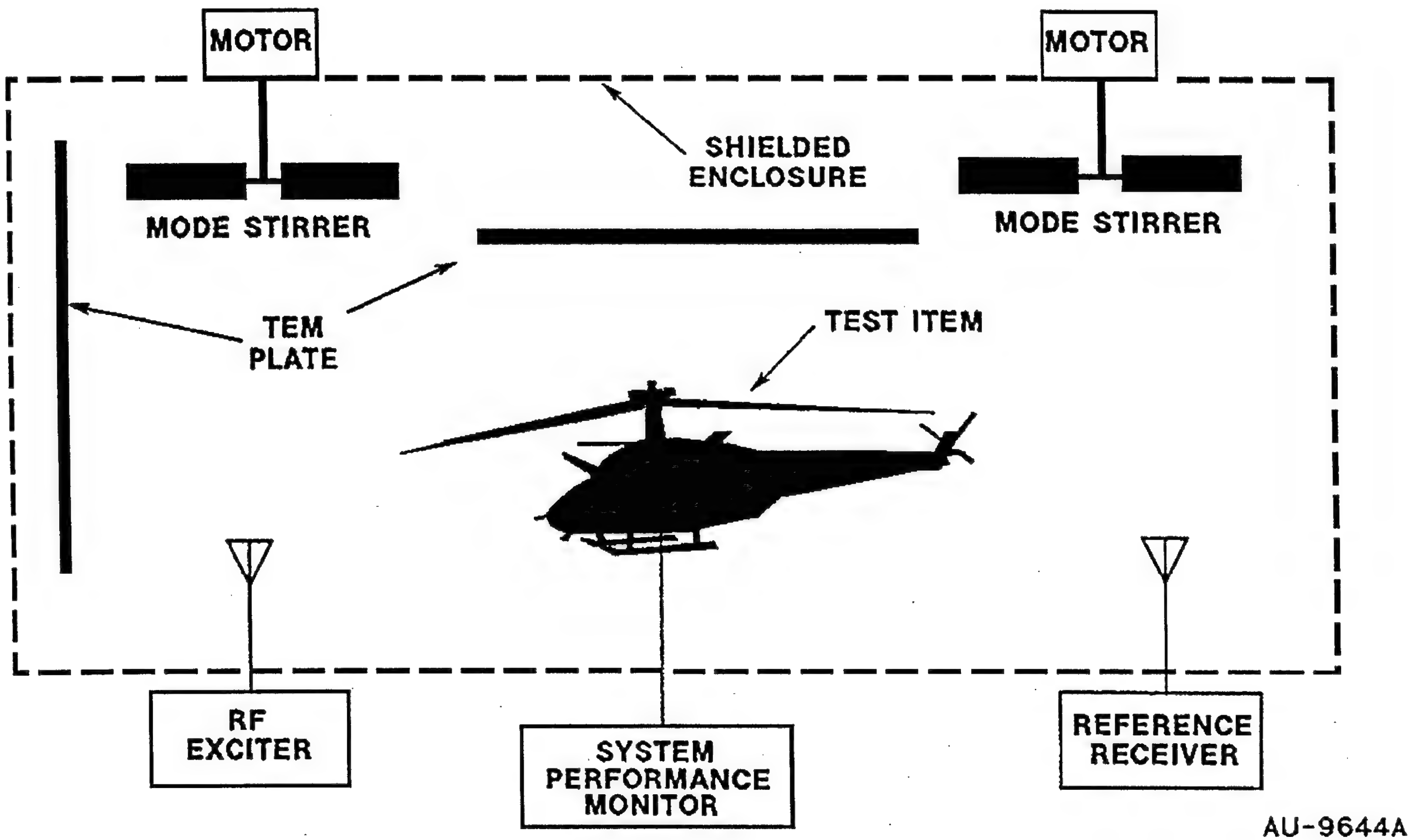
- Large Mode-Stirred Chamber Test Facility At NAWCAD Patuxent River
  - Install into Existing Installed System Test Facility (Air Combat Environment T&E Facility)
- Use Past Army Design Effort To Save Time And Design Costs
  - Fort Huachuca Proposal, 127 x 113 x 50
- Pursue DOD Central T&E Investment (CTEIP) Funding

TEMMS FACILITY
DESCRIPTION

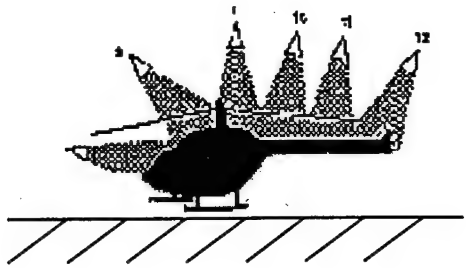
A Large Shielded Enclosure Which Permits Efficient Generation Of Intense, High-Level Electric Fields For the RF Illumination Of Large Test Volumes Within A Controlled Environment

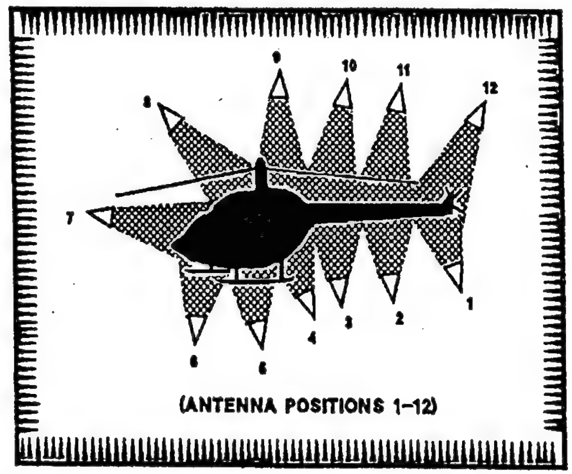
TEMMS CHAMBER

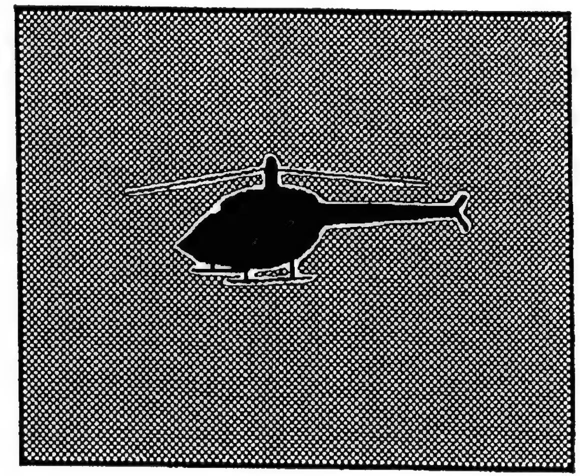
HOW IT WORKS



TEMMS VERSUS ANECHOIC
COMPARISON OF ILLUMINATION



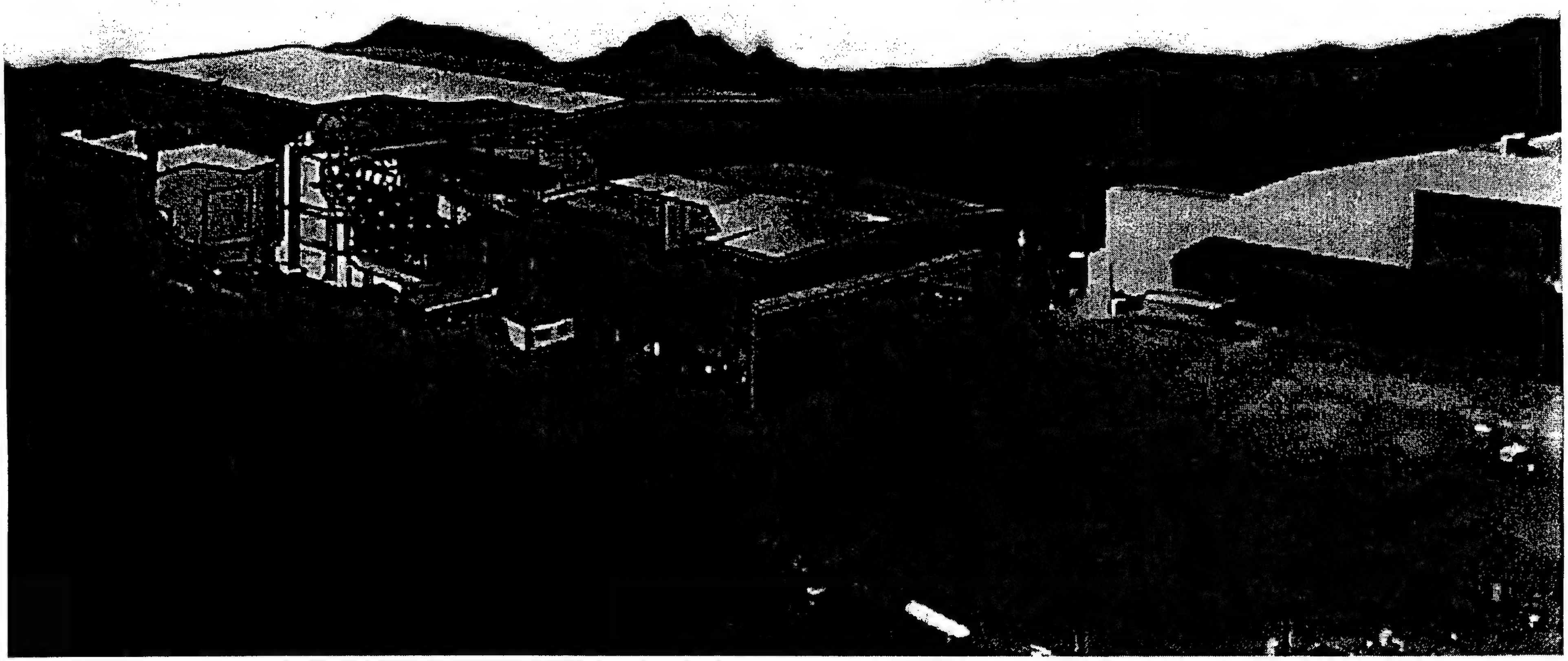




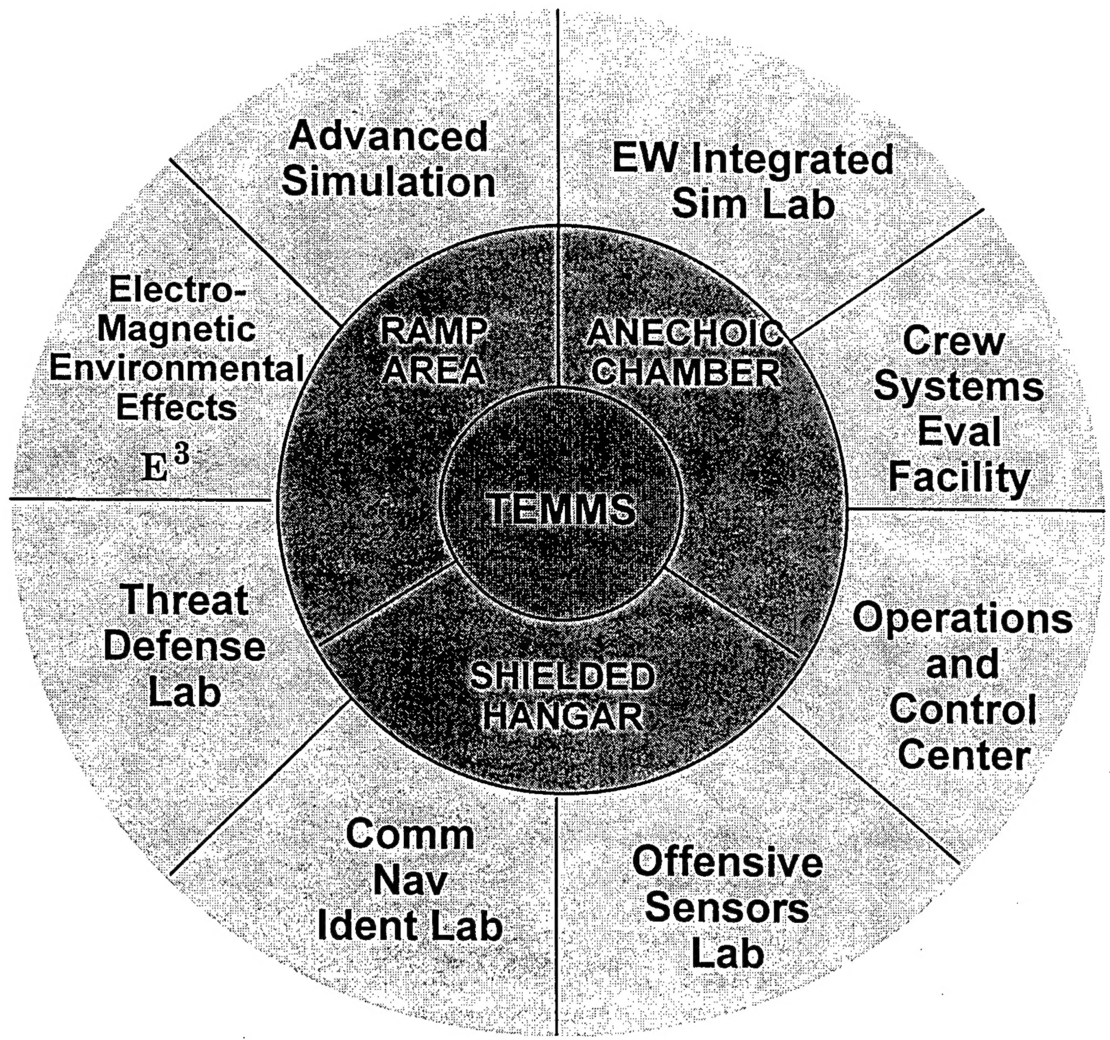
OUTDOOR

ANECHOIC

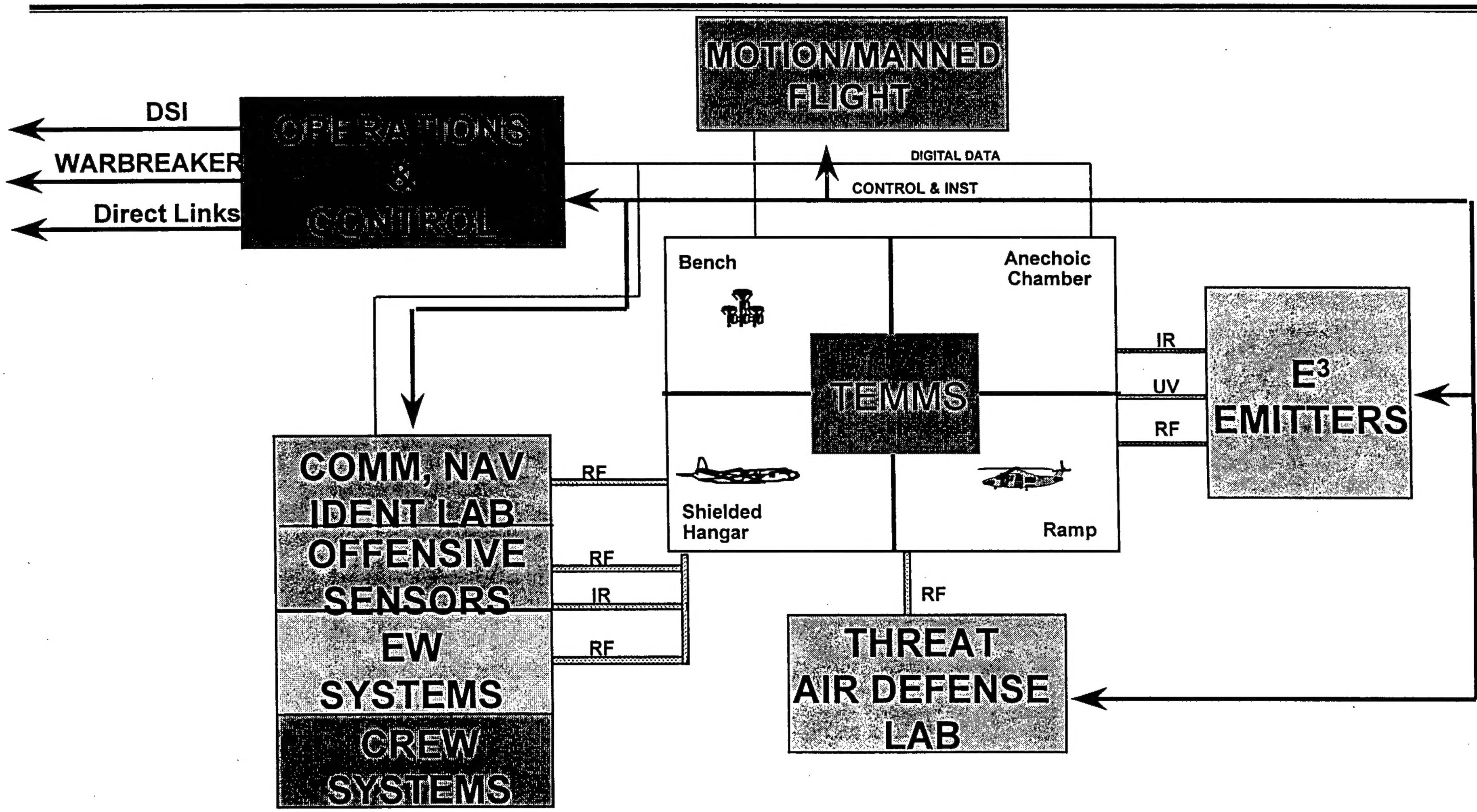
MODE-STIR



INSTALLED SYSTEM TEST FACILITY
TEST CAPABILITIES



ISTF ARCHITECTURE



Warfare Simulation

Man-in-the-Loop Simulation

Hardware-in-the-Loop Stimulation

Installed Systems Test

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TEMMS STATUS

Technology

- Army TEM-Reverb 10% Scale Built/Validated Technology
- Mode-Stir Technology Mature and Rapidly Proliferating
- Efficiencies Higher Than Originally Estimated

Facility (Army)

- Original Design at 65%
- Navy Sponsored SBIR to Review Original Design for Technology Improvements

Location (Navy)

- MILCON P-538
- EA and Soil Samples Complete (Location is Original Large Anechoic Chamber site)

SUMMARY

- Mode-Stir Facility Provides Cost Effective E^3 Test Tool
- Proposing A Large Mode-Stir Facility Capable Of Testing Large Scale Weapon System
- Based on Army's TEM Reverb Design
- Integrate Into Existing HSTF Architecture at Pax River
- Joint Army/Navy Program